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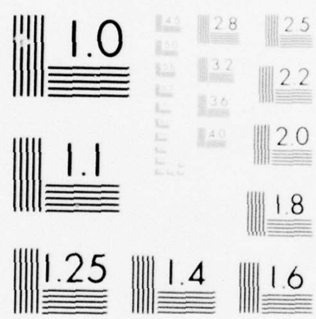
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PHASE I OF A PROGRAM TO DESIGN AND TEST A BALLOON SYSTEM FOR SHIPBOARD LAUNCH,

Report No. R-0777002

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Project Manager

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CONTENTS

1.0 INTRODUCTION

This report, Raven Industries, Inc., Report No. R-0777002, is submitted to satisfy the contractual requirements of Phase I of Government Contract N00014-77-C-0170. The submittal of this report will complete Phase I of the program. Raven is funded to continue the effort under Phase II of the contract which continues through October 1977.

The purpose of the program is to develop a balloon system which can be launched from the deck of a ship, by inexperienced personnel, and will support a 15.0 lb. payload at an altitude of 70,000 feet for a duration of 4-12 hours. The balloon system must be rugged enough to permit reliable deployment in wind velocities up to 45 knots.

Phase I of the program was limited to evaluating several different balloon configurations and selecting that configuration which best meets the problems associated with high wind inflation. Several candidate balloon configurations were evaluated to determine handling characteristics and durability when launched in the intended environment.

All balloon configurations tested had one common characteristic. They all incorporated a reinforced upper balloon or section of a balloon to withstand the abuse associated with windy inflation. It was planned that the lower main balloon or the lower portion of the balloon would be folded and packaged for in-flight deployment at a predetermined time following launch. Such an arrangement exposes only the relatively small reinforced upper balloon or reinforced upper section of the main balloon to the adverse inflation environment. This reduces the space required for launch and maintains the more fragile main balloon in the protective packing container until after launch.

Two basic balloon configurations were evaluated: a dual (or tandem) natural shaped balloon system, and a reefed cylindrical balloon system. During Phase I only the upper tow balloon (in the case of the natural shaped tandem balloon configuration) and the reefed portion of main balloon (in the case of the cylindrical balloon) were tested and evaluated.

Contained in the remaining portions of this report is a discussion of the analysis, balloon configuration description and testing which were conducted in evaluating the various balloon configurations. And finally, a description of that balloon configuration which was selected as best meeting program objectives which will be pursued further in Phase II of the program is described and the reasons for its selection are presented.

2.0 PROGRAM DESCRIPTION

The major constraints in launching a balloon from the deck of a ship are the wind and space requirements. The balloon, as it is being inflated, is very susceptible to damage and failure from buffeting in the wind and from impacting on the ground and into surrounding obstacles. Most balloon launches occur under low wind or no wind situations and require a long area in which to lay the balloon out prior to launch. The length of the balloon train as it is normally configured at launch is not compatible with the space that is available on most ships. Therefore, it was obvious from the beginning of the program that it was necessary to keep the amount of balloon exposed to the adverse weather conditions at a minimum and to protect that area of the balloon which was exposed. A balloon system which is designed to float at 70,000 feet has approximately 6% of the available balloon volume inflated with helium at launch. The remaining volume is provided to allow the gas to expand such that the balloon will be full at float altitude. Therefore, the plan was to keep all of the balloon system folded and packed except that which was required to provide the lifting volume during launch and ascent. That area of the balloon which would serve as the lifting volume was fabricated from either a durable material or was provided with a protective outer shell.

Two basic balloon designs were evaluated for this program. They consisted of a system of two, tandem, natural shaped balloons and a reefed cylindrical shaped balloon system. As stated previously, Phase I of this program was concerned primarily with the inflation characteristics and durability of the small natural shaped tow balloon (in the case of the natural shaped balloon system) and the upper reefed portion of the cylindrical balloon (in the case of the cylindrical balloon system).

The natural shaped balloon has a gore pattern which is mathematically derived to provide zero circumferential stress. This balloon configuration possesses excellent lift to weight efficiency which is only slightly less than the lift to weight ratio of a sphere. Therefore, a balloon of minimum weight, and size, can be offered with this configuration. Another benefit to be gained using tandem, natural shaped balloons is that the fitting between the two balloons offers an ideal location and a means for upper balloon inflation. This fitting is also ideally suited for restraining the balloon system during inflation and can also serve as a gas transfer mechanism between the tow balloon and the main balloon during ascent.

The main disadvantage of the tandem, natural shaped balloon system is its ascent velocity. Based on past experience ascent rates of 500-800 ft/min (fpm) are common with a free lift at launch of 10-15%.

The cylindrical balloon design is a hybrid between a natural shape and a cylinder shape. The upper portion of the balloon is that of a natural shaped balloon from the equator on up. The center section is that of a cylinder with a diameter equal to the maximum diameter of the natural shape. The lower section of the balloon is that portion of the natural shape from the equator down. A cylindrical shaped balloon has a length to maximum diameter ratio of approximately 3.

The main advantage of the cylindrical shaped balloon is its fast ascent rate. Based on past experience this type of balloon can achieve ascent rates of 750-1000 fpm with a free lift of 10-15%.

Disadvantages of the cylindrical shaped balloon include its lower volume to weight ratio. Thus, a cylindrical shaped balloon will weigh more than a natural shaped balloon of equal volume using similar materials. In addition, a cylindrical shaped balloon does not offer a good location for balloon inflation. Inflation is usually accomplished through a duct which passes through the balloon wall in the upper portion of the balloon. The duct is long enough to extend to or below the base end fitting. It is usually fabricated of polyethylene film which has proven adequate for low or no wind inflations, but has not been proven in a high wind environment. Another disadvantage of the cylindrical shaped balloon system is that it requires a reefing sleeve to separate the upper portion of the balloon from the main balloon body. Reefing is usually accomplished with a line securely cinched around the balloon film. A line cutter is provided to cut the line in flight allowing the main balloon to fully inflate. Because the balloon film is relatively thin, 0.75 mil, reliability is decreased due to the possibility of film damage during the reefing and/or dereefing operation.

Payload weight as provided at the beginning of the program was 8.0 lbs. Preliminary calculations showed that a main balloon having a volume of 6,000 cubic feet would be required to support the 8.0 lb. payload at 70,000 feet. A tow balloon having a lift of 25.0 lbs. was determined as adequate based on these parameters. This necessitated a tow balloon having a volume of 375-400 cubic feet at launch. However, early into the program it was learned that the payload weight had increased to 15.0 lbs. and that a termination timer and a parachute would also be required

in the flight train. The additional weight of these items plus the additional weight of the payload caused an increase in system weight and therefore in balloon size. System weight fluctuated, generally increasing, throughout the duration of the program as system components became better defined. All natural shaped balloon inflation tests were run using a balloon having a volume of 750 cubic feet. Inflation tests of the cylindrical shaped balloon were run on balloons having a reefed volume of 900-1200 cubic feet.

A number of formal tests were conducted to evaluate the various selected configurations of the natural and cylindrical shaped tow balloons. In addition to the formal tests, informal inflation tests were performed inside a building to determine diffuser performance, balloon inner and outer shell alignments, shape and lift. A detailed description of the various formal tests and the test results can be obtained by referring to the test reports contained in the back of this report. Contained in this section is a brief discussion of each formal test.

The first series of inflation tests were conducted 5 April 1977. They consisted of two natural shaped balloon configurations and two reefed cylindrical balloon configurations. A description of the four balloon designs as tested is contained in the following:

A. Natural shaped balloon, 12 foot diameter (750 cubic feet) constructed of 2 mil polyethylene.

B. Natural shaped balloon system, 12 foot diameter (750 cubic feet) with a 0.75 mil polyethylene inner shell and a 1.6 oz/yd^2 calendered nylon fabric outer shell.

C. Upper portion of cylindrical shaped balloon with an approximate volume of 1200 cubic feet having an inner gas barrier of 0.75 mil polyethylene and an outer shell of 1.6 oz/yd^2 calendered woven nylon fabric.

D. Upper portion of cylindrical balloon with an approximate volume of 1200 cubic feet having an inner gas barrier of 0.75 mil polyethylene and an outer shell of 2 mil polyethylene.

All four balloons had an inflation duct located 18 inches up from the base of the balloon. The tests were conducted in winds of 21 knots steady with gusts to 28 knots. Inflation of Design A was completed without apparent damage to the balloon. However, approximately 5 minutes after inflation closer inspection revealed that there were several small holes in the balloon where it had made contact with the pavement. The balloon was unstable and struck the blacktop on numerous occasions.

Designs B, C and D all experienced a common mode of failure. Namely, in the process of inflation the instability and constant motion of the balloon caused the inflation duct to fail at the balloon wall. Each balloon failed at somewhat different levels of inflation, but in all cases the failure indicated a weakness in the design.

Based on these tests the following conclusions were reached:

(1) Inflation by means of the duct attached to the side wall of the balloon is inadequate from a strength standpoint and also from the fact that it requires experienced personnel to operate the inflation hose. Therefore on future tests it was decided that for the natural shaped balloons inflation would be accomplished through the base end fitting, and on cylindrical balloons inflation would be accomplished through an inflation fitting attached to a reinforced area in the balloon wall.

(2) Based on the results of the first test it was determined that 2 mil polyethylene is not a suitable material as the gas barrier without an outer shell to protect it.

The second series of tests was conducted on 25 April 1977. Wind conditions were in the range of 10-22 mph. For this series of tests four balloons were again evaluated: two of the natural shaped configuration and two of the cylindrical shaped configuration. A description of the balloons is contained in the following:

A. Upper portion of cylindrical shaped balloon with an approximate volume of 1200 cubic feet constructed with a 0.75 mil polyethylene gas barrier and an outer shell of 1.6 oz/yd^2 calendered nylon.

B. Natural shaped balloon system, 12 foot diameter (750 cubic feet) constructed with a 0.75 mil polyethylene gas barrier and 1.6 oz/yd^2 calendered nylon outer shell.

C. Upper portion of cylindrical shaped balloon with an approximate volume of 1200 cubic feet, having an inner gas barrier of 0.75 mil polyethylene and an outer shell of 2 mil polyethylene.

D. Natural shaped balloon, 12 foot diameter (750 cubic feet), constructed with a 1.5 mil polyethylene inner shell and a 1.6 oz/yd^2 calendered nylon outer shell.

The natural shaped balloons had an inflation fitting located in the base end fitting and the cylindrical shaped balloon had an inflation fitting attached to a reinforced area in the balloon wall approximately 18 inches above the base end

fitting. The two natural shaped balloons were inflated in times of 2 minutes for one and 45 seconds for the other. That balloon which was inflated in 45 seconds exhibited a great deal of flutter in the area immediately above the end fitting. Both balloons were inflated without incident. The balloons were left tethered to their anchor point for approximately 15 minutes before the top end fitting of the balloon was removed and the balloon deflated. Inspection of the balloon showed no damage to the inner gas barrier.

The cylindrical shaped balloon Design A which had the 1.6 oz/yd^2 calendered nylon outer shell was inflated successfully. The balloon was left anchored to its tie-down point for approximately 15 minutes after which the balloon top end fitting was removed and the balloon investigated for damage. No damage was observed.

The other cylindrical shaped balloon, Design C, was unsuccessful. After approximately 50% balloon inflation, it was observed that the inner cloth diffuser had failed which resulted in balloon damage near the inflation fitting.

Two changes were made to future cylindrical balloon designs based on the results of these tests. The first design change was to move the reefing position on the cylindrical balloon up approximately 3 feet. The reason was to increase the base angle at the bottom of the balloon and result in a balloon which has a tighter skin after inflation. It was thought that a tighter skin would result in improved balloon performance during inflation and during the short period the balloon would be tethered prior to launch.

The second design change is dictated by the fact that the diffuser failed in the Design C cylindrical balloon. Therefore, on future cylindrical shaped balloons the diffuser was strengthened.

The third series of tests was conducted on 3 May 1977. The tests consisted of a cylindrical shaped reefed balloon with a 3 foot shorter gore length than that on previously tested cylindrical balloons. This balloon had a volume of 750-800 cubic feet, depending on the degree of inflation. Due to the extra fullness at the base of the balloon caused by the reefing line, it is difficult to define when this type of balloon is "full". This inflation had two main objectives. One objective was to evaluate the shape of the balloon with the reduced gore length, and the second objective was to evaluate the performance of the new reinforced diffuser. Both of these design changes were suggested based on previous tests.

The balloon was inflated indoors so that the shape could be better evaluated and a free lift determined so that a volume could be computed. Based on the appearance of the balloon after inflation, it was generally agreed that the shape was better than it had been on previously tested cylindrical balloons and that this would be the shape we would use on future balloons of this configuration. In addition, no damage was observed in the diffuser following inflation. Therefore, this diffuser design was also selected for future cylindrical balloon configurations.

The next series of tests were conducted on 4 May 1977. The purpose of these tests was to evaluate the performance of two balloon designs by inflating them in winds somewhat stronger than had been experienced on previous tests. All previous cloth outer shells had been fabricated from a calendered woven nylon fabric. The calendering process affords the fabric somewhat water repellent but does not make it water proof. Concern was registered as to what the effect would be on balloon performance if this material was used in a situation where the balloon would become wet during inflation from either rain or seawater spray. Therefore, for this series of tests, two balloons were tested, one with a calendered nylon outer shell, and the second with a urethane coated nylon outer shell. The purpose of the test was to evaluate inflation performance of both balloons after being soaked or submersed in water. Another purpose of the test was to determine whether a fixed end fitting mount would affect balloon inflation performance. The two balloons tested were as follows:

A. Natural shaped balloon constructed with a 1.5 mil polyethylene gas barrier and a 1.6 oz/yd^2 calendered nylon outer shell.

B. Natural shaped balloon constructed with a 0.75 mil polyethylene inner shell and a 2.2 oz/yd^2 urethane coated nylon outer shell.

Both balloons had a volume of 750 cubic feet. Originally it had been planned to conduct these tests with winds of 25-30 knots. Since the winds were not adequate during the days available for testing, it was arranged to rent an airplane from a local firm, point the airplane into the wind and inflate the balloons to the rear of the airplane. A Cherokee 140 was used as a test airplane. A hand-held anomometer was used to determine the rpm's necessary to provide winds in the desired test range.

The first balloon tested, Design A, was tested with a velocity profile that ranged from 20-40 mph over the test section. The balloon was inflated in 1 minute 5 seconds

with no damage inflicted to the balloon during or after inflation. Wetness of the outer shell had no noticable effect on balloon inflation or performance.

The second balloon, Design B, was inflated with the base fitting rigidly mounted in a vertical position. The airplane was operated such as to provide a wind velocity in the test section of 30-40 mph. The balloon was inflated with no apparent damage and was left tethered for a couple minutes. Total inflation time for this balloon was 1 minute 28 seconds.

The final tests were conducted on 16 June 1977. This series of tests consisted of 13 balloon inflations conducted in NASA Langley's open throat wind tunnel. The tests were conducted in the wind tunnel because wind velocity could be preselected and precisely controlled for each test. Test objective was to evaluate the performance of four different balloon designs at various wind velocities starting with lower velocities and gradually working to higher velocities up to a maximum of 45 knots. Also to be evaluated during wind tunnel tests was the ability to inflate a balloon without assistance in controlling the balloon during inflation, and also to determine the effect a rigid mount would have on balloon performance.

The four balloon designs which were considered included the following:

A. Natural shaped balloon constructed with 0.75 mil polyethylene gas barrier and an outer shell of 1.6 oz/yd^2 calendered nylon. Five units of this design were fabricated.

B. Upper portion of cylindrical shaped balloon with 0.75 mil polyethylene gas barrier and an outer shell of 1.6 oz/yd^2 calendered nylon. Four units of this design were fabricated.

C. Natural shaped balloon constructed with 1.5 mil polyethylene gas barrier and an outer shell of 1.6 oz/yd^2 calendered nylon. Two units of this design were fabricated.

D. Natural shaped balloon constructed with 0.75 mil polyethylene gas barrier and an outer shell of urethane coated nylon. Two units of this design were fabricated.

Contained in the enclosed drawing, Raven Industries Drawing No. R-15770, is the layout of the test sequence for the natural shaped balloons as prepared jointly by Raven Industries and NADC contract personnel. The plan was prepared as a

guideline to help determine the test conditions for each test based on the success or failure of the previous test. The enclosed Drawing A-15771 includes the wind tunnel test procedure for the cylindrical shaped balloons. The test plan as shown in these two drawings, except for a few cases, was followed for selecting test conditions.

Contained in the enclosed table is a list of test procedure and data as obtained during the wind tunnel tests. As can be seen from the table, the only balloon failures occurred in the A and B design. All A designs worked with wind velocities through 40 knots. However, three successive failures on the A design were incurred at velocities of 45 knots. The only other failure occurred in Test #5 on the B balloon design. In this case the inflation fitting pulled out of the balloon wall. This may have been due to poor end fitting installation, but watching the actual test and the movies of the test, it is obvious that this sort of a situation may be a problem on all similar balloon inflations. Another general observation based on witnessing the tests and from the movies is that the natural shaped balloons appeared to take more abuse during inflation than did the cylindrical shaped balloons. However, as a participant in the tests, it was significantly more difficult to inflate the cylindrical shaped balloon because of the necessity of inflating through the fitting attached to the side wall of the balloon.

Based on all the testing conducted throughout Phase I of this program, and especially upon the results of the wind tunnel tests, the Design C as tested in the wind tunnel was selected as the best configuration for meeting overall program requirements and reliability. Design C was a natural shaped balloon constructed of 1.5 mil polyethylene gas barrier and an outer shell of 1.6 oz/yd^2 calendered nylon. The cylindrical shaped balloon, Design B, was not selected because of difficulties encountered during balloon inflation. In addition, the disadvantages as noted earlier in this report associated with the cylindrical shaped balloon also weighed heavily in this decision. These included the problems associated with reefing a cylindrical balloon and inflation of such a balloon in the adverse wind conditions associated with this program. Design A, the natural shaped balloon constructed with 0.75 mil polyethylene gas barrier and an outer shell of 1.6 oz/yd^2 calendered nylon, was not selected because of the three failures which occurred in the wind tunnel tests at 45 knots. Design D offered no weight advantage over Design C and its inner gas barrier, being constructed of 0.75 mil polyethylene, would not be as reliable a gas barrier as the 1.5 mil polyethylene which was included in the selected design, Design C. The design is defined by Raven Drawing No. A-15989.

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WIND TUNNEL TEST RESULTS

Test Date: 16 June 1977

Test No.	Balloon Config.	Velocity (Knots)	Assisted (Yes or No)	Restrained (Yes or No)	Inflation Time	Remarks
1	A-113	30	Yes	No	1 min 6 sec	Inflation good, 30-60 seconds after inflation balloon hit raw ends of steel cable inflicting small hole in balloon. Cable covered prior to further tests.
2	A-108	40	Yes	No	59 sec	Inflation successful. No damage to balloon even though it hit 3/8" cable around edge of test platform--hard on numerous occasions. Cable removed prior to further testing.
3	A-120	45	Yes	No	53 sec	Inflation was successful; however immediately after completion of inflation inner balloon damage occurred. Inspection revealed 5-6 ft tear along and near one seam.
4	B-111	35	Yes	No	1 min 46 sec	Inflation successful. Noticably less balloon motion and stress than on natural shaped balloons. Free lift 37 lbs.
5	B-110	40	Yes	No	1 min 5 sec	Inflation fitting pulled out of balloon at approximately 50% inflation.
6	B-108	40	Yes	No	2 min 19 sec	Inflation successful - no balloon damage. Net lift - 48 lbs.
7	B-109	45	Yes	No	1 min 26 sec	Inflation successful - no balloon damage. Net lift - 41 lbs.
8	A-114	45	Yes	No	1 min 18 sec	Inflation successful; however immediately after completion of inflation inner balloon damage occurred. Inspection revealed 6-7 ft tear along and near one seam.

Wind Tunnel Test Results (Continued)

Test No.	Balloon Config.	Velocity (Knots)	Assisted (Yes or No)	Restrained (Yes or No)	Inflation Time	Remarks
9	C-115	45	Yes	No	43 sec	Inflation successful; however inflation fitting pulled out of end fitting at 80-90% inflation. Net lift - 25 lbs.
10	C-116	45	Yes	Yes	55 sec	Inflation successful. No balloon damage. Net lift - 34 lbs.
11	D-121	45	Yes	Yes	1 min 10 sec	Inflation successful. No balloon damage. Net lift - 36 lbs.
12	D-112	45	Yes	No	58 sec	Inflation successful. No balloon damage. Balloon inflated to superpressure.
13	A-117	45	Yes	Yes	----	Inflation successful until 80-90% inflation. At this time complete balloon failure occurred on both inner and outer balloon a short distance above base fitting.

Contained in the table below is a breakdown of system component weights as they are estimated at the conclusion of Phase I:

Balloon Component	Weight (lbs.)
Upper Balloon	9.5
Top Fitting	0.5
Interface Fitting	4.0
ECL Timer	1.75
Bottom Fitting	0.5
Parachute	1.5
Container	3.0
Baro/Time Switch with Power Supply	1.0
Miscellaneous	2.0
Payload	15.0
Main Balloon	12.0
TOTAL WEIGHT	50.7 lbs.

Based on these numbers the balloon configuration which will be used for Phase II of the program is the natural shaped tow balloon having a volume of 900 cubic feet, fabricated using 1.50 mil polyethylene for the inner gas barrier and a 1.6 oz/yd^2 calendered nylon as the outer shell. The main balloon will be a 12,600 cubic foot natural shaped balloon fabricated of 0.75 mil polyethylene. The size of the tow and main balloon will be updated as Phase II progresses and the component weights become better defined.

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APPENDIX

TEST REPORT

Contract No. N00014-77-C-0170 Test Date: 5 April 1977

Report Prepared by: K. L. TeKrony

Participants (other than Raven Personnel):
Jim Roach - NADC
Harold Dewhirst - NADC
Mike Evanick - ONR

Wind Conditions: 21 knots steady with gusts to 28 knots

Test Objective:

The purpose of the tests was to evaluate the inflation performance of four different balloon designs in winds. The four balloons had volumes ranging from 750 ft^3 to 1200 ft^3 and are envisioned as being the upper portion of a larger balloon system. The upper balloon will have sufficient lift to support the packed main balloon with associated hardware and payload.

Test Description:

Four balloon designs were evaluated. These included the following:

A. Natural shaped balloon system 12 ft. diameter constructed of 2 mil polyethylene.

B. Natural shaped balloon system constructed with a 3/4 mil polyethylene inner shell and a 1.6 oz/yd^2 nylon fabric outer shell.

C. Upper portion of cylindrical shaped balloon with an approximate volume of 1200 cubic feet having an inner gas barrier of 3/4 mil polyethylene and an outer shell of 1.6 oz/yd^2 woven nylon.

D. Upper portion of cylindrical balloon with an approximate volume of 1200 cubic feet having an inner gas barrier of 3/4 mil polyethylene and an outer shell of 2 mil polyethylene.

All four balloons tested had one common design detail. All had an inflation duct located approximately 18 inches up from the base of the balloon.

Test Results:

Design A and B were inflated simultaneously. Inflation of design A was accomplished in approximately one minute. The balloon was very unstable during inflation coming in contact with the asphalt surface numerous times. Inflation was difficult but was accomplished without apparent damage to the balloon. However, after approximately five minutes and closer inspection, it was apparent that there were some small holes in the balloon.

Inflation of design B progressed satisfactorily until approximately 75% of the balloon was inflated. At this time the unstable motion of the balloon caused the inflation duct to separate from the balloon wall. This necessitated terminating the inflation.

Designs C and D were inflated simultaneously. Inflation of design C was difficult but it appeared that it was accomplished without damage to the balloon. However, very shortly after all helium had been transferred to the balloon, the inflation duct separated from the balloon before the inflation hose could be removed.

Design D was approximately 50% inflated when balloon damage occurred near the inflation duct resulting in termination of the test.

Conclusions:

The most obvious conclusion reached as the result of these tests was that the inflation ducts were not adequate to withstand the forces experienced in so windy an environment. During the past test meetings with NADC and ONR personnel, NADC personnel were of the opinion that an inflation duct, even if constructed sufficiently strong to withstand inflation forces, is not an acceptable method of attaining balloon inflation. Duct inflation requires a certain amount of expertise which may not be available and it requires more balloon manhandling and personnel movement than desired for a shipboard launch.

Therefore, future natural shaped balloons will be constructed with an inflation fitting on the base end fitting of the balloon to which the inflation hose will be attached. The cylindrical balloons will be constructed with an inflation fitting in the side wall of the balloon, near the base, to which the inflation hose will be attached.

Another conclusion drawn from these tests is that a single wall balloon, even a 2 mil balloon, is not adequate to withstand the hostile environment to which these balloons are subjected. Therefore, future balloons will be double wall construction.

Future Tests:

Another four balloons are being constructed for testing approximately 25 April 1977. These balloons consist of one each of the following designs:

1. Natural shaped balloon having a .75 mil polyethylene gas barrier and a 1.6 oz/yd^2 nylon fabric outer shell.
2. Natural shaped balloon having a 1.5 mil polyethylene gas barrier and a 1.6 oz/yd^2 nylon fabric outer shell.
3. Cylindrical shaped balloon having a .75 mil polyethylene gas barrier and a 1.6 oz/yd^2 nylon fabric outer shell.
4. Cylindrical shaped balloon having a .75 mil polyethylene gas barrier and a 2 mil polyethylene outer shell.

Following these tests balloons will be fabricated for testing in the wind tunnel at NASA Langley. These tests are tentatively scheduled for the week of 23 May 1977.

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TEST REPORT

CONTRACT NO. N00014-77-C-0170

Test Date: 25 April 1977

Report Prepared by: K. L. TeKrony

Participants (other than Raven personnel):

Harold Dewhirst - NADC
William F. Cross - ONR

Winds Conditions: 10-22 mph (per local weather station)
14-18 mph as measured by hand-held anomometer on site

Test Objective:

The purpose of the test was to evaluate the inflation performance of four different balloon designs. The four balloons had volumes ranging from 750 ft^3 to 1200 ft^3 and are envisioned as being the upper portion of a larger balloon system. The upper balloon will have sufficient lift to support the packed main balloon with associated hardware and payload. These tests were a followup to those tests conducted on 5 April 1977 and incorporated the design changes as dictated by the previous test results.

Test Description:

Four balloon designs were evaluated. These included the following:

A. Upper portion of cylindrical shaped balloon with an approximate volume of 1200 ft^3 constructed with a 3/4 mil polyethylene gas barrier and an outer shell of 1.6 oz/yd^2 calendared nylon.

B. Natural shaped balloon constructed with a 3/4 mil polyethylene gas barrier and a 1.6 oz/yd^2 calendared nylon outer shell.

C. Upper portion of cylindrical shaped balloon with an approximate volume of 1200 ft^3, having an inner gas barrier of 3/4 mil polyethylene and an outer shell of 2 mil polyethylene.

D. Natural shaped balloon system constructed with a 1.5 mil polyethylene inner shell and a 1.6 oz/yd^2 calendared nylon outer shell.

The natural shaped balloons were approximately 12 foot diameter with a volume of 750 ft^3, and the cylindrical shaped balloons had a volume of approximately 1200 ft^3. The two natural shaped balloons were designed with an inflation fitting and diffuser built into the bottom end fitting. The cylindrical balloons were designed with a reinforced inflation fitting constructed in the side wall of the balloon 18 inches up from the reefing point. A nylon cloth diffuser was attached to the inflation fitting.

Test Results:

Design A was the first balloon tested. The balloon was inflated using 5 helium bottles manifolded together. Initial pressure in the 5 tanks was 2000 psi. The balloon was inflated with one person holding the top end fitting until the balloon was approximately 75% inflated, at which time the top of the balloon was released and allowed to seek its own position based on winds and lift. Inflation required approximately 2 minutes and was uneventful. Pressure in the helium tanks at the end of the test was approximately zero. Therefore, the inflation time could have been shortened somewhat had additional helium been available to maintain a higher pressure.

Following the test the balloon was left attached to the ground anchor while the second balloon was being inflated. Approximately 15 minutes later (after inflation of the second balloon) the line cutter used to dereef the cylindrical balloon was fired allowing helium to transfer into the lower 3 foot section of the balloon. The primary purpose of this portion of the test was to demonstrate that the balloon could be reefed, inflated and dereefed without damage to the inner gas barrier. Upon investigation of the balloon, no damage was observed.

Design B was also inflated using 5 helium bottles manifolded together. Initial pressure in the tanks was 2000 psi with a final pressure after inflation of 500 psi. This balloon too was inflated with a person restraining the top end fitting until the balloon was approximately 75% inflated. Balloon inflation was accomplished through the inflation fitting located in the base end fitting. Inflation required 1 minute 15 seconds and was uneventful. Once the balloon was completely inflated with the skin tight, the balloon was quite stable when left attached to its anchor point. The balloon was left anchored for approximately 15 minutes after which time the base end fitting was removed and the balloon deflated. During the deflation operation it was possible to look on the inside of the balloon and check for inner and outer balloon alignment which appeared to be very good.

Design C was inflated using 5 helium bottles manifolded together. The bottles had an initial pressure of 2000 psi and a final

pressure of approximately zero. The initial portion of the balloon inflation was very similar to that of the others. However, at approximately 50% balloon inflation it was obvious that some failure had resulted in the inner balloon near the inflation fitting. Therefore, inflation was halted and the balloon inspected for damage. Inspection revealed that the inner cloth diffuser had failed which resulted in balloon damage near the inflation fitting.

Design D was inflated in the same manner as was Design B. Initial pressure in the helium bottles was 2000 psi and the final pressure was approximately 500 psi. Balloon inflation was somewhat faster than that in the other natural shaped balloon, Design B. This was evidenced by the additional flutter of the balloon near the end fitting. Total inflation time for this balloon was 45 seconds. Even though there was considerable flutter near the fitting, no balloon damage was sustained. Inflation was uneventful with no damage to the balloon. Inspection of the balloon showed that the outer shell was twisted approximately 1 gore position from that of the inner shell. Both end fittings were installed with the gores aligned properly. However, somehow during folding or inflation the inner balloon was rotated 1 gore from that of the outer balloon. This did not affect balloon inflation or tethered performance. The balloon was left anchored for approximately 10 minutes. As with the other natural shaped balloon it was quite stable in the tethered mode.

The balloon was deflated by removing the base end fitting. During deflation the balloon was evaluated on the inside for inner and outer balloon alignment. As stated previously, the only misalignment occurred at the top and bottom end fitting. Throughout the remainder of the balloon alignment appeared to be very good.

Conclusions:

1. Based on the results of the four tests conducted, the natural shaped designs were judged to be those designs which we should use in our wind tunnel tests. Another point of information gathered from these tests is that inflation time of approximately 1 minute to 1½ minutes is about optimum for this balloon. Inflation times shorter than this subject the balloon skin to considerable flutter.

2. Two changes are proposed on our future cylindrical balloon models. The first proposed design change is to move the reefing position on the cylindrical balloon up approximately 3 feet. This will have the affect of increasing the base angle at the bottom of the balloon and will result in a balloon which has a tighter skin after inflation. A tighter skin should result in

improved balloon performance during inflation and during the short period it will be tethered prior to launch. The other change will be to incorporate a reinforced diffuser at the inflation fitting. The diffuser which we used during these tests is a standard diffuser which is normally used on our Carrier balloons. We also have conducted previous tests with this diffuser in launch conditions similar to those conducted during this test with good results. However, based on the one failure we saw on Design C, this component will be strengthened on future units.

Future Tests:

An additional three engineering tests are planned prior to the test sequence at NASA Langley. These will include two natural shaped balloons with designs identical to Designs B and D as described in this test report. These two balloons will be tested at winds above 25 mph at Raven facilities with no assistance during inflation. Both of these balloons will be inflated with the end fitting restrained. One balloon will have water sprayed on it prior to inflation to evaluate balloon inflation when wet.

An additional cylindrical shaped balloon will be fabricated and tested in an effort to reduce the overall size of this balloon while maintaining sufficient volume to provide the required lift. This will be accomplished by moving the reefing point up approximately 3 feet.

A test plan for the NASA Langley wind tunnel test is being prepared and will be provided within a couple of days.

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TEST REPORT

CONTRACT NO. N00014-77-C-0170

Test Date: 3 May 1977

Report Prepared by: K. L. TeKrony

Participants (other than Raven Personnel):

Harold Dewhirst - NADC
Jim Roach - NADC

Test Objective:

The primary purpose of this test was to evaluate the shape and determine the actual volume of the cylindrical shaped balloon with a gore length shorter than those tested during the inflations on 25 April 1977. A secondary objective was to evaluate a stronger and somewhat larger diffuser than those used in the previous tests.

Gore length on those cylindrical balloons tested previously was 21.0 ft. and that of the subject test balloon was 18.0 ft. The previous balloons tested had considerable excess fabric during and after inflation. Less excess fabric should improve the stability and therefore the reliability of the balloon.

Test Description:

The balloon was inflated in the balloon plant using five helium bottles manifolded together. Initial pressure was 2000 psi with a pressure of 200 psi remaining in the bottles after balloon inflation. Inflation was rather slow, requiring three minutes to completely inflate the balloon.

Test Results:

The balloon was inflated so a slight internal pressure existed in the balloon. The resulting shape was similar to that of an onion with a larger diameter than height. Due to the reefing required at the base there were many tucks in the fabric causing an uneven balloon contour. However, the primary objective of providing a balloon with less excess material during and after inflation was achieved.

Free lift of the balloon after inflation was 39.0 pounds with the test balloon and hardware weighing 15.75 pounds. This

computes to a volume of 831 ft^3 which is slightly less than computations show are necessary to provide a gross inflation of 56.5 pounds (calculated system weight + 20% free lift).

Conclusions:

The principle of shortening the gore length of the cylindrical balloon to reduce excess material during and after inflation was successful. Those units fabricated for the wind tunnel tests will have a gore length of 18.8 ft., which will provide a volume of 558 ft^3 which will be sufficient to provide the required 56.5 pounds of lift.

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TEST REPORT

CONTRACT NO. N00014-77-C-0170

Test Date: 4 May 1977

Report Prepared by: K. L. TeKrony

Participants (other than Raven Personnel):

Harold Dewhirst, NADC
Jim Roach - NADC
William F. Cross - ONR

Wind Conditions: 16-18 knots (per local weather station and as measured by hand-held anomometer)

Test Objective:

The purpose of the test was to evaluate the inflation performance of two different balloon designs. Both balloons were the upper portion of the natural shaped balloon and were the same two balloon designs as were described as Design B and D in the test report dated 25 April 1977. Balloon Design B was a natural shaped balloon constructed with a 3/4 mil polyethylene gas barrier and a 1.6 oz/yd^2 calendared nylon outer shell. Balloon Design D was a natural shaped balloon constructed with a 1.5 mil polyethylene inner shell and a 1.6 oz/yd^2 calendared nylon outer shell.

After the test of 25 April 1977 the balloons were inspected for damage. None being found it was decided these two balloons would be retested under more severe test conditions. The purpose of one of the tests was to determine whether a wet outer balloon would cause a gross deterioration of inflation performance. The purpose of the second test was to determine whether a fixed end fitting mount would grossly decrease the balloon performance.

Test Description and Results:

As stated previously, the two balloons tested were those which had previously been used and are as follows:

First balloon -- Natural shaped balloon constructed with a 1.5 mil polyethylene gas barrier and a 1.6 oz/yd^2 calendared nylon outer shell.

Second balloon -- Natural shaped balloon constructed with a 3/4 mil polyethylene inner shell and a 2.2 oz/yd^2 coated nylon outer shell.

Both balloons had a volume of 750 cubic feet. The only design detail difference between these balloons and those tested on 25 April 1977 was that these balloons had a nylon cloth diffuser attached to the end fitting on the inside of the balloon. The purpose of the diffuser was to reduce the balloon flutter which had been observed on earlier tests near the end fitting.

Originally it was planned to conduct these tests with winds of 25-30 knots. Since the wind conditions were not adequate during the days available for testing, it was arranged to rent an airplane from a local firm, point the airplane into the wind and inflate the balloons to the rear of the airplane. A Cherokee 140 was used as the test airplane.

Using a hand-held anomometer, it was determined that an engine speed of 2000 rpm's the wind profile in the test area varied from 20-40 mph. These were the test conditions selected for the first balloon inflation. The first balloon, prior to inflation, was submersed in water. The balloon was then inflated with the airplane engines operating at 2000 rpm's using five helium bottles manifolded together. Initial pressure of the helium tanks was 2000 psi with a final pressure after balloon inflation of 400 psi. Inflation time was 1 minute 5 seconds and the velocity profile in the area of the balloon varied from 20-40 mph with an average of approximately 30 mph.

The balloon was inflated through a fitting on the base fitting of the balloon with one person assisting inflation by restraining the top end fitting. Inflation was uneventful with a minimum amount of flutter at the base fitting caused by inflation gas. The balloon bounced around from side to side and rearward making numerous contacts with the pavement on which the balloon was inflated. No apparent damage was sustained by the envelope. The envelope was left in this condition for approximately three or four minutes after which the airplane was stopped and the balloon deflated.

The wetness of the outer shell had no notable effect on balloon inflation or performance. In addition, the nylon diffuser at the base of the balloon appeared to alleviate the flutter problem which had been observed on previous tests.

The second balloon was inflated with the base fitting rigidly mounted in a vertical position. The airplane was operated with its engines at 2200 rpm's which resulted in a velocity profile of 30-40 mph in the area where the balloon was inflated. The balloon was inflated using five helium bottles manifolded together having an initial pressure of 2000 psi and a pressure after balloon inflation of 250 psi. Inflation was accomplished using the inflation fitting on the base fitting of the balloon. The balloon was assisted during its initial 10-20% by restraining the top end fitting after which the end fitting was released and the balloon allowed to seek its own position throughout the remainder

of the inflation. The only problem observed in inflating the second balloon was keeping the fabric loose above the top end fitting. The natural tendency for a balloon inflation with the end fitting held vertical and rigid is for the wind to pull the top of the balloon directly across the end fitting restricting the flow and causing considerable flutter to the balloon in this area.

The balloon was inflated with no apparent damage and was left tethered for a couple of minutes. Total inflation time for the second balloon was 1 minute 28 seconds.

Conclusions:

Based upon results of the two tests conducted, it appears that water will not drastically affect the inflation performance of a balloon with a calendared nylon outer shell. In addition, it appeared that the new nylon diffuser attached to the base fitting on the inside of the balloon alleviated much of the flutter which had been observed in previous tests.

The second test verified that it is possible to inflate the balloon with fairly high winds using a rigid end fitting mount. However, inflation did demonstrate that it is desirable to have either a non-rigid end fitting mount or be able to rotate the rigid mount at least in one axis.